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SR.N6 HOVERCRAFT
COLD WEATHER TRIALS IN SWEDEN
17TH FEBRUARY TO 26TH MARCH, 1966.

Publication SP.1294 April 1966

THE BRITISH HOVERCRAFT CORPORATION LIMITED EAST COWES ISLE OF WIGHT ENGLAND

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MAIN SUMMARY

During February and March 1966 an SR.N6 hovercraft No./009 was based in Sweden with the object of carrying out Cold Weather Operational Trials. The craft was operated along the Baltic coast of Sweden from Malmo in the South up to Soderhamn in the North; total running time was approximately 62 hours.

The range of day temperatures in which the craft operated was from +10°C to -14°C and the coldest night temperature recorded was -24°C. The hovercraft was not put under cover at any time during the trials. During the journey from Malmo to Soderhamn, a distance of approximately 600 nautical miles, all types of water, ice and snow surface conditions were encountered.

It was shown that SR.N6 could be operated most satisfactorily over smooth ice or ice slightly covered with snow. Ground speeds up to 75 knots were easily obtained under these conditions. Over slightly rough ice surfaces, with irregularities up to 1.5 feet it was possible to cruise at 35 knots, and over rough ice surfaces with boulders up to 3.5 feet it was possible to pick a route at 20 to 25 knots. Navigation in the archipelago off Stockholm was simple and it was shown that a mean speed of 35 knots presented no difficulties whilst manoeuvring among the islands. Several long sorties were made over snow, in places up to 2 feet deep. No difficulties were encountered. It was shown however that jet type rear skirts were unsuitable for operation in snow with a surface temperature around 0°C.; the unjetted skirt had to be used.

Trial installations of several types of de-icing equipment were fitted to the craft. However, the suitability of these installations was not fully tested, since only on one short occasion was it possible to find water at the same time that the air temperature was low enough to produce severe icing conditions. A trial installation of ducting air from the craft plenum to the engine air intake was also made and this was very satisfactory in keeping snow from the engine intake filters. It was not used regularly however as the smoky air from the engine tailpipes contaminated the compressor and necessitated more frequent engine washing. There was also some loss of engine power.

The engineering installations of the craft were trouble-free throughout the whole trials period. Apart from the normal daily inspection and the replacement of an engine I.G.V. actuator, no work was necessary on any craft system. The radar functioned perfectly at all times and without it navigation among the islands would have been very difficult. On several occasions sorties were made in poor visibility which stopped the movement of all other vehicles, but were possible for the hovercraft on account of the excellent performance of the radar.

The skirts were inspected at regular intervals as the trials progressed. There were no signs of wear or tear of the main skirts at any time. The rear skirts were fitted with rubbing strips at the jet and these strips became torn at one or two places after approximately 30 hours. They were cut away from the skirts when the jet was deleted half way through the trials. Skirts freezing into the ice was a regular

occurance but presented no difficulties as they could be freed by running the engine and with a little help from a shovel and ice axe.

Generally, SR.N6 showed that it was an excellent means of transport over ice and snow. It gave an extremely comfortable ride to its passengers and was able to operate most successfully among the archipelagos. It was most convenient to be able to alight on the ice at any spot around an island or along the mainland and embark or disembark passengers etc. without the need to look for a harbour or other type of base.

1. INTRODUCTION

During the period February 16th to March 26th 1966, an SR.N6 hovercraft was operated on trials around the south and east coast of Sweden. The object of these trials was to investigate the ability of hovercraft to operate under very low temperature conditions and over the ice and snow of a Baltic winter. The hovercraft selected was Serial No. N6/009 which had previously been operating in Norway and Denmark. This craft was in fact the first SR.N6 to be built and its operating time on arrival in Sweden was approximately 930 hours, and the engine running time was 537 hours.

Two SR.N6 craft were operated from Århus in Denmark to Malmö on February 14th. Messrs. Kockums provided an excellent 'Hover-Terminal' for the craft in part of their shipyard. It was subsequently decided that only one craft would be necessary; therefore the second machine (No.N6/011) was later shipped to England.

2. TRIALS SCHEDULE

The trials were supported financially by the Swedish Royal Navy, the British Ministry of Aviation, and Westland Aircraft Ltd. It was agreed that no fixed programme of trials should be laid down, but that the main points of common interest be listed and the engineers responsible for the trials to decide how best the work might be completed. Operating time for the craft was estimated at 50 hours, and a period of 30 days was considered a reasonable target.

The main points of the test schedule were as follows:-

(a) Craft performance and handling properties:-

- (i) over smooth ice
- (ii) transition from water to ice and vice versa
- (iii) over rough and broken ice, to determine limiting conditions
- (iv) over loose dry snow and wet slush snow
- (v) in open water with air temperatures below zero.

(b) Navigation

- (i) ability to operate through narrow channels and among islands
- (ii) operation in reduced visibility or at night
- (iii) functioning of radar and its value for high speed navigation.

(c) Protection against icing of craft

If icing of structure etc. is experienced in (a) (v) above, investigate anti-icing devices.

(d) Crew training

Arrange a short period for initial pilot familiarisation of Swedish Navy Officers.

(e) General craft engineering and installations

Record and assess all engineering defects, peculiarities, etc. which may be the result of cold weather or ice conditions, with special attention to skirt wear over all ice and snow surfaces.

Special attention to the effects of low temperatures on the ability of the ground crews to complete their normal day-to-day maintenance, or any work on the craft during the period.

3. SUMMARY OF TRIALS COMPLETED

3.1. GENERAL

The winter conditions during the latter part of January, through February and March were the most severe experienced in Sweden within the last 50 years. For example, the Sound between Malmo and Copenhagen was completely frozen for at least two weeks, a most unusual occurrence. Further north in the Stockholm area the amount of ice in the Baltic was such that many ships were frozen in, and the 2 or 3 feet of snow north of Stockholm was a rare occurrence. In these circumstances it was anticipated that the whole trials programme might well be completed from the base at Malmo. However, after three weeks at Malmo sufficient experience had been gained to allow a much more ambitious programme to be attempted, viz. a coastal trip up to Stockholm (approximately 400 n.miles), followed by a further trip northwards to Soderhamn (approximately 170 n.miles north of Stockholm), where it was decided to set up a second base at a subsidiary plant at Kockums. Finally, a sortie back to Stockholm was arranged, and since the time allowed for the trials would by then have run out, the craft was to be shipped back to the U.K. from Stockholm.

3.2. ABBREVIATED DIARY OF EVENTS

A map of the area of operation is given in fig.1 and the abbreviated diary of events begins overleaf.

Fig. 1 MAP OF AREA OF OPERATIONS

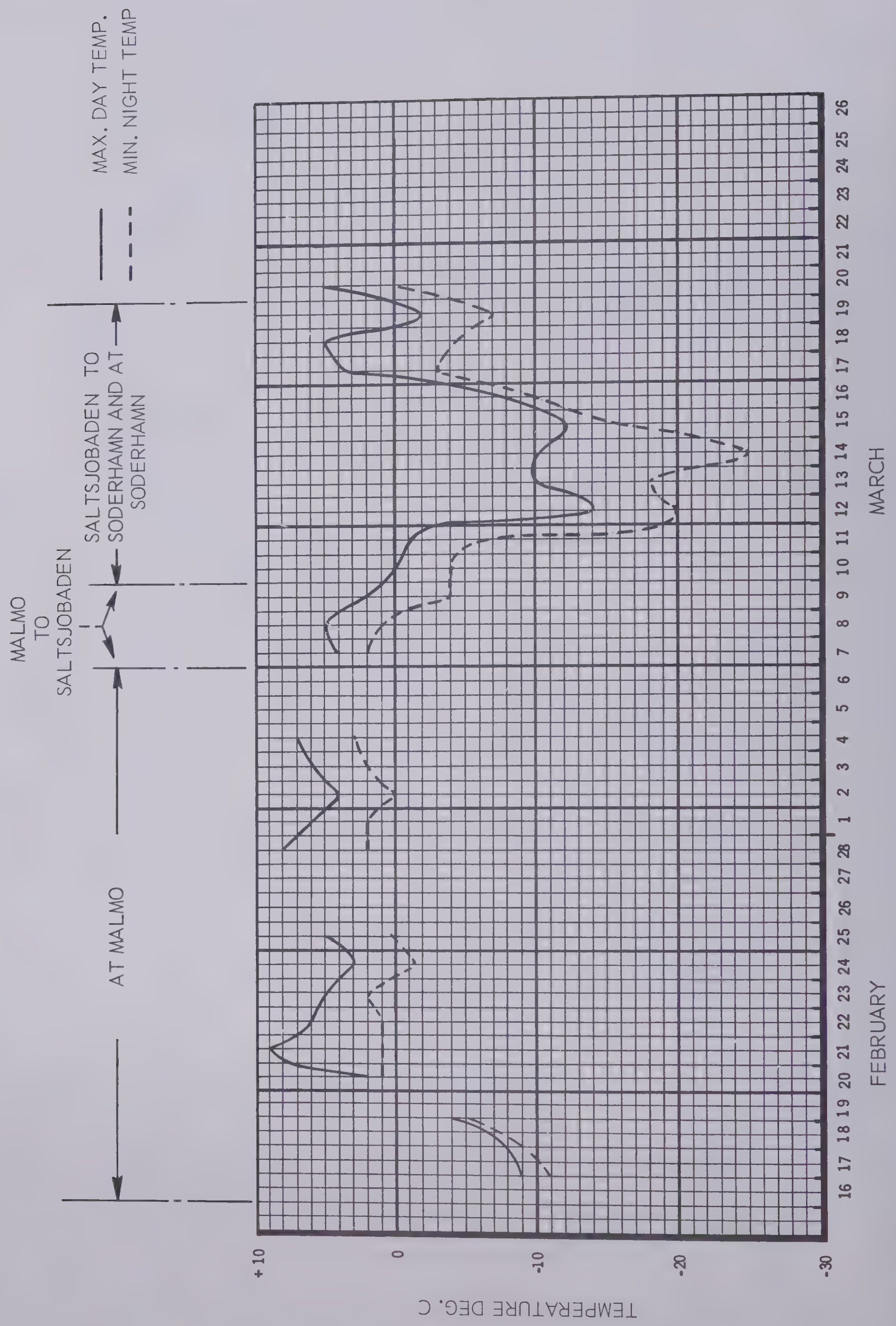

Fig. 2 DAILY RECORD OF TEMPERATURES

Date	Remarks	Running Time Hour	Min.
14.2.66.	Craft No. /009 and /011 arrived Malmo from Arhus. Hover terminal being prepared.		
16.2.66.	Preparation and planning meeting with Swedish liaison officers.		
17.2.66.	Sortie No.1 in area of Saltholm. Sortie No.2 same area, Commodore Wallen as guest.	1	45
18.2.66.	Preparations of terminal continued.		
21.2.66.	Sortie No.3 to Skanor area. Sortie No.4. Exercise over saltings, some piloting experience for Capt.Lundberg and Capt.Bjernekull.	2	10
22.2.66.	Sorties No.5 and 6, trials over screw ice, Saltholm area and along Danish coast, Copenhagen and southwards.	2	55
23.2.66.	Sorties No.7,8,9,10. Rough ice trials Skanor and Falsterbo area, returned via Falsterbo Canal	2	25
24.2.66.	Lifted /009 to examine skirts; all satisfactory. Demonstration sortie by /011 Sortie No.11. /011 - port quarter slightly damaged whilst manoeuvring at terminal.	1	15
25.2.66.	Sortie No.12; demonstration to Admiral Lindermalm, Skanor district. Visibility about 100 yards.	2	10
26.2.66.	/009, changed engine IGV actuator and double-washed engine. /011 Repairs to port side.		
27.2.66.	Stand-down day.		
28.2.66.	Sortie No.13; aerial photographs of craft over ice .	1	20
1.3.66.	Sortie No.14, bad visibility, pilot-experience over ice for I.H.T.U. officer.	0	50
2.3.66.	Sorties No.15,16. Photographic day for M.O.A., W.A.L. and Swedish TV.	2	50
3.3.66.	Visibility poor but one trip over rough ice possible, Sortie 17.	0	40
4.3.66.	Demonstration to Shipping Company visitors, Sortie No.18.	0	50

Date	Remarks	Running Time Hour	Min.
5.3.66.	Lifted /009 to inspect skirts; all satisfactory.		
6.3.66.	Lowered craft ready for early start next day.		
7.3.66.	Visibility almost zero until midday. Sortie 19, from Malmo to Simrishamn after lunch.	3	15
8.3.66.	Sortie No.20. Simrishamn to Bergkvara; refuelled . Sortie No.21. Bergkvara to Oskarshamn; refuelled.	5	05
9.3.66.	Sortie No.22. Oskarshamn to Arkesund; refuelled. Sortie No.23. Arkesund to Dolaro; refuelled. Sortie No.24. Dolara to Saltsjobaden.	5	10
10.3.66.	Inspected craft and then stood down for rest of day.		
11.3.66.	At Saltsjobaden. Sorties No.25 and 26. Demonstrations to Swedish Navy officers. Sortie No.27. Tests in soft snow conditions	2	55
12.3.66.	Fairly heavy snow at 08.30 hrs. Sortie No.28. Saltsjobaden to Oregrund;refuelled. Sortie No.29. Oregrund to Gavle; refuelled. Gale force wind and snow on last sortie.	6	20
13.3.66.	At Gavle, inspected craft in morning. Stand-down after lunch.		
14.3.66.	Sortie No.30, Gavle to Soderhamn. Prepared to lift craft to inspect skirts. Fitted plenum engine air intakes.	2	00
15.3.66.	Sortie No.31. Trials on new intakes and reconnaissance of ice/snow conditions northwards.	1	35
16.3.66.	Sortie No.32. Followed ice barrier northwards to search for water. Operations in deep snow investigated.	2	25
17.3.66. 18.3.66.	Fitted de-icing trial installations.		
19.3.66.	Sortie No.33. Checked de-icing equipment. Air temperature too high at ice hole we had previously blown with TNT.	1	20
20.3.66.	Temperature above freezing; no trials.		

Date	Remarks	Running Time Hour	Min.
21.3.66.	Sortie No.34. Departed Soderhamn for Oregrund. Sortie No.35. Oregrund to Norrtalje.		
22.3.66.	Sortie No.36. Norrtalje to Saltsjobaden with Naval party aboard.	2	15
23.3.66.	Sortie No.37. At Saltsjobaden. Icing trials carried out on pneumatic panel on front corner of port pannier and fabric panel on port plenum. No de-icing fluid used, but no ice formed.	1	10
	Sortie No.38, with Naval personnel to measure the magnetic signature of the craft over water.	0	25
24.3.66.	Sorties 39,40,41. Three demonstrations, during which speeds of 60 and 64 knots were obtained.	2	30
25.3.66.	Sortie Nos.42,43,44. Three demonstrations.		
26.3.66.	Sortie Nos. 45,46,47. Left Saltsjobaden for Stockholm for demonstrations. Returned to Saltsjobaden for pilot familiarisation.	6	15
	Total hours	61	40

4. RESULTS OF TRIALS

4.1. GENERAL

The trials may be conveniently divided into the following phases:

(a) Tests in the Malmo area.

(b) The trip up the coast from Malmo to Soderhamn.

(c) Trials at Soderhamn.

(d) Return from Soderhamn to Stockholm and demonstrations in that area.

4.2. AT MALMO

Initially the weather was very cold and the greater part of the Sound was covered with thick smooth ice. Wide channels had been broken through this ice for shipping lanes, but these quickly froze over. The west coast of the island of Saltholm was well packed with screw ice; this area was therefore most suitable for working-up trials. Techniques were developed for running and manoeuvring on the smooth

ice and for transition from water to ice, etc. It was possible to choose areas of screwed up ice with progressively rougher surfaces and to find out the most satisfactory method of operating over it.

4.2.1. Operation from calm water to smooth ice and vice versa

This presented no difficulty in either direction. Naturally, an experienced driver reduced speed before the transition if the previous speed was greater than approximately 40 knots. The slight change of trim, either bow up or down, depending upon the transition, could normally be checked by elevator control. Brief measurements of speed change from water to ice, for constant settings, appeared to be between 6 and 8 knots. This speed over ice, however, might well have built up had the runs been continued for long distances.

4.2.2. Operation over smooth ice

This gives the most pleasant ride that any hovercraft designer can desire. In light winds the pilot has good manoeuvring control, but at all speeds it is of the greatest importance to anticipate all manoeuvres well in advance. The lack of water drag from the skirts is most pronounced and if a turn is attempted in a normal over-water method, the radius may be three or four times greater than expected. The normal turning technique developed was to reduce trpm to the top of the'red band'to produce skirt friction, and then to decrease speed further by reducing or reversing propeller pitch. With the craft then turned through the required angle, power and pitch could be restored and the new heading maintained.

In high wind conditions it was quite satisfactory to run downwind at very low trpm, making good use of skirt friction. The interesting point was that this type of operation appeared to have no serious effects on skirt wear. Figure 3 shows the craft operating over typical smooth ice and fig.4 shows the track of a run over snow-covered smooth ice at low trpm. Stopping distances were not measured accurately over a speed range, but were enormously increased as compared with over-water distances; a half pirouette after reducing speed to about 20 knots, was the normal stopping technique.

4.2.3. Operation over rough ice

The technique developed for this operation was to slow down to about 10 knots at the approach to the rough areas, then to increase trpm to approximately 20,000 and set the propeller pitch to 4° or 5°; this gave good control conditions and a speed of from 15 to 25 knots. Rough ice surfaces up to 15 in. presented no difficulties and the craft's course could be maintained at only slightly reduced speed. Ice roughness up to 2 feet was negotiated for quite long periods but it was necessary to pick a route rather than hold a course. Tests were made through wide areas of screw ice with surface irregularities in excess of 4 ft. It was normally possible to pick a path through this type of ice, which did not necessitate driving over boulders higher than 3 to 3.5 feet. It was interesting to note the use the pilot made of propeller pitch in these manoeuvres; having swung the bow on to the required heading, coarse use of positive propeller pitch took the craft through the various narrow lanes and gaps. At least 15 knots was possible through

this rough ice. A typical ice field of the type found around Malmo is shown in fig. 5 and 6.

4.2.4. Operations over rough land surfaces

There appeared to be considerable interest in the ability of the SR.N6 to operate over land as well as water so several short passages were made over small rough areas of Northern Saltholm and later over fields, marshes and a golf course at Skanor. At this latter village an embankment carrying a roadway separated the northern saltings and estuary from a large southern area. A photograph of the craft crossing this road is given in fig.7.

5. SORTIE FROM MALMO TO SODERHAMN

5.1. GENERAL

During this sortie visiting officers from the Swedish Navy joined the craft. They were perhaps fortunate in their choice of time since during the few days of this exercise, almost every type of weather condition was experienced. At the start of the journey it was clearly laid down that no attempts were being made to set up speed records or to try to make the trip in the shortest possible time. It was agreed that the objects were to investigate the craft's performance over the various sea and ice conditions which were encountered. The Navy officers expressed a wish that when nearing the Stockholm Archipelago the course should be deliberately set to show the craft's ability to navigate and manoeuvre among these islands.

5.2. MALMO TO SIMRISHAMN

Date	7th March 1966
Route distance	83 n.m.
Route time	2 hr. 28 min.
Mean speed	33 kt.

Remarks:

(a) Wind, approx. 10 kt. S.W. Air temp. +5°C. Mainly open water at start, but 25% ice after first hour. Wind increased to 20 kt. but visibility decreased, and for last $1\frac{1}{2}$ hr. maximum visibility was 150 yd., often down to 50 yds.

(b) Wave swell up to almost 4 ft. x 60 ft; when approaching an ice field the area of broken ice around it had to be approached with caution since the swell was throwing up the broken ice and it was advisable not to negotiate this at high speed. It was also necessary to pick a good approach to the solid ice where the shoulder was not too high.

(c) Harbour at Simrishamn; very rough ice and no landing place. Went to beach outside harbour, approach being over huge boulders of piled-up broken ice. The 'parking' site for the night is shown in fig.8.

(d) Main comment. Excellent navigation allowed a good mean speed in very bad visibility. No other craft, including helicopters, were able to operate.

5.3. SIMRISHAMN TO BERGKVARA

Date	8th March 1966
Route distance	85 n.m.
Route time	2 hr. 50 min.
Mean speed	30 kt.

Remarks:

(a) Wind light SW at start, increasing to 15 kt. Visibility 2 miles. Air temperature +3° to +5°C. Sea calm for first few miles then 4 to 5 ft. swell across the bay. At the turning point of Karlskvona, sea was rough and confused. Several large ice-fields had to be traversed, very rough in places.

(b) Harbour at Bergkava; some smooth ice at jetty which just took the weight of craft for refuelling.

(c) Main comment. This sortie demonstrated that in a rough sea, both following and on the beam, the craft can give a very comfortable ride, but that speed and power settings are important. 2 or 3 kt. excess speed changes a comfortable armchair-like ride into something much more approaching the slamming of a hard-chine craft.

5.4. BERGKVARA TO OSKARSHAMN

Date	8th March 1966
Route distance	62 n.m.
Route time	1 hr. 40 min.
Mean speed	37 kt.

Remarks:

(a) Wind, 20 kt. SSW. Visibility, 4 miles. Sea, slight chop for first 20 min. then ice all the way. Ice smooth with no snow on it. Broken in places by ship routes.

(b) Wind on port quarter giving high ground speed and drift angle. Speed at times estimated at 70 kt. but 50 kt. was target speed. This smooth ice was almost as clean as a skating rink and was virtually frictionless.

(c) Oskarshamn harbour was a complete mass of broken up and refrozen ice blocks. The SR.N6 was manoeuvred around the whole area for approximately 25 min. looking for a suitable refuelling berth. Finally taken back out of the harbour to a small beach.

5.5. OSKARSHAMN TO ARKESUND

Date	9th March 1966
Route distance	83 n.m.
Route time	2 hr. 5 min.
Mean speed	39 kt.

Remarks:

(a) Wind, 10-12 kt. westerly. Temperature, $0^{\circ}C$. Visibility good, sunshine and clear sky. Over choppy water for first 25 min. then turned to port into the Archipelago north of Storklappen. From then onwards clean smooth ice, but many islands.

(b) Navigation at high speed (40-50 kt.) is possible among these thousands of islands by a trained crew. Naturally, not having to stay in a charted water channel makes hovercraft operation much easier than with a ship or boat. Many short cuts were taken through narrow channels and over the edge of some islands.

(c) Arkesund, drove straight up on to snow and grass for refuelling, see fig.9.

(d) Main comment The SR.N6 showed up extremely well in its manoeuvrability among the islands. The Commander's anticipation was excellent throughout the sortie, particularly as there was a full beam wind for most of the period.

5.6. ARKESUND TO DALARO

Date	9th March 1966
Route distance	66 n.m.
Route time	1 hr. 30 min.
Mean speed	44 kt.

Remarks:

(a) Weather conditions as for 5.5 above. First half of trip was along a water lane $\frac{1}{4}$ to 1 mile wide with an ice barrier on each side, often up to 15 ft. high; some very rough patches of ice had to be crossed at times. After re-entering the archipelago the ice was smooth and clean. Most of the trip was completed at a speed greater than 50 kt.

(b) Speed change measured when going from absolutely calm water to smooth ice, +6 knots.

5.7. DALARO TO SALTSJOBADEN

Date	9th March 1966
Route distance	22 n.m.
Route time	39 min.
Mean speed	34 kt.

Remarks:

(a) Weather as for para. 5.5 and 5.6. This was a short sortie to bring SR.N6 to a place conveniently near Stockholm. Almost the whole trip was made over smooth ice.

(b) Really a sightseeing pleasure trip on a beautiful sunny afternoon, through one of the finest archipelagoes in the world. Nobody else was moving over or through the ice among these islands. The base at Saltsjobaden is shown in fig.10.

5.8. SALTSJOBADEN TO OREGRUND

Date	12th March 1966
Route distance	95 n.m.
Route time	3 hr. 5 min.
Mean speed	31 kt.

Remarks:

(a) Wind 10 to 15 kt. increasing to 20 to 25 kt. north-easterly. Visibility approximately 1 mile, low cloud and some snow. Temperature -2°C., falling to -10° at Oregrund.

(b) The start of this sortie was through very narrow channels up to Vaxholmn. From there onwards the ice was covered with a layer of snow. Initially this was only 2 or 3 in. deep and was being blown by the strong wind. Off Oregrund the snow layer was 12 to 18 in. deep. This did not cause any operating difficulty but the driving snow and huge drift angle did not make navigation easy.

(c) Main comment This was the first operation over deep snow and was completely successful.

5.9. OREGRUND TO GAVLE

Date	12th March 1966
Route distance	48 n.m.
Route time	2 hr. 24 min.
Mean speed	20 kt.

Remarks:

(a) This trip was in a 35 kt. wind on the starboard bow which at times gusted to 45 kt. Visibility was mostly less than 100 yd. due mainly to driven snow.

(b) The surface was generally rough ice but covered with about 2 ft. of snow; it was often impossible to distinguish between small islands and ice barriers. It was however quite possible to pick a route on radar and then creep through at about 15 kt.

(c) The arrival at Gavle in the prevailing weather conditions caused astonishment. Vehicles do not come in over the ice in winter and certainly not in this type of weather!

(d) Main comment

This was excellent navigation and piloting by the flight crew. Pictures of the craft at the Gavle base are given in fig.11 and 12.

5.10. GAVLE TO SODERHAMN

Date	14th March 1966
Route distance	44 n.m.
Route time	1 hr. 13 min.
Mean speed	36 kt.

Remarks:

(a) Wind 10 kt. northerly; visibility good, bright sunshine, temperature - 10°C.

(b) Most of the trip was over rough ice which was covered by at least 2 ft. of snow. The main obstacles to avoid were jagged 'teeth' of ice which projected 4,5 and 6 ft. out of the snow at frequent intervals.

(c) The welcome to the newly prepared hover terminal at Soderhamn Verkstader AB was most enthusiastic. Everything asked for had been provided. Photographs of the base at Soderhamn are shown in figs. 13 and 14.

5.11. OVERALL DISTANCE

	N.M.	HR.	MIN.
stage 1	83	2	28
2	85	2	50
3	62	1	40
4	83	2	05
5	66	1	30
6	22	0	39
7	95	3	05
8	48	2	24
9	44	1	13
Total:	588	17	54

Average speed, whole trip = 33 knots.

6. TRIALS AT SODERHAMN

6.1. GENERAL

Day and night temperatures in the area were well below zero and had been for a considerable period. Generally the whole town and surrounding district was under 3 to $3\frac{1}{2}$ feet of snow. Day temperatures averaged -10°C and night -20°C. See fig.2. It was planned therefore to investigate: (1) engine air intake from the plenum of the craft, (2) build-up of snow in rear skirts and (3) the effect of several simple de-icing systems.

6.2. COLLECTION OF SNOW IN REAR SKIRTS

Experience of operating over snow in Denmark had shown the

possibility of the skirts collecting large quantities of snow at the aft end. On the three occasions when this happened, snow and air temperature conditions were almost similar, and the indications were that the phenomenon was associated with a very narrow temperature range, probably $0^{\circ} \pm 2^{\circ}C$. The jet-type rear skirt bags (as fitted in Denmark) were therefore fitted to /009 to investigate the problem more fully and, by blanking off the jet for part of the trials period, to determine whether the non-jet bag would overcome it.

On two occasions snow was collected in the rear bags during normal operations and each time the snow surface temperature was approximately $0^{\circ}C$. On the first day new snow had just fallen and on the second day the surface snow which had been many degrees below zero had been warmed by the sun to a 'wet' zero. The results were precisely as had previously been experienced; the stern became heavy and the skirts trailed progressively more deeply in the snow until the pilot was no longer able to steer the craft satisfactorily. Normally one skirt collected more snow than the other and the craft trimmed stern down, with a slight roll towards the heavy side. Having reached this condition, it was necessary to stop and shovel the snow out before proceeding any further. After the jet at the bottom of the bags had been blanked off by bolting a strip of material along its whole length no further filling with snow was experienced, even though operations were made at the critical snow surface temperature.

One other case of snow in the rear bags appeared to be significantly different from those described above, but an analysis shows that it probably had a similar origin. On arrival at Gavle after approximately 6 hours operating it was noted that the aft bags were half full of large balls of snow, frozen to almost solid ice, see fig.15. The craft had left Saltsjobaden early in the morning, some snow falling, and the temperature $0^{\circ}C$ to $-2^{\circ}C$. The temperature fell steadily all the way to Oregrund when it was $-10^{\circ}C$ and to $-14^{\circ}C$ at Gavle. It is therefore almost certain that the snow was collected during the first mile or two after leaving Saltsjobaden and was then constantly rolled around inside the skirt and frozen into the condition found at Gavle.

6.3. DE-ICING INSTALLATIONS

It has always been intended that when operating in cold climates, the upswept tail pipe extensions should be removed from the engine. The very large amount of hot air then being taken into the fan and circulated around the whole craft forms an excellent anti-icing device for the whole of the plenum area. Furthermore, the remaining hot air from the engine tailpipe is taken through the propeller and over the fins and elevators. While no great claims are made for this as a de-icing installation, the effects can only be beneficial.

The only case of icing on SR.N5 or SR.N6 so far reported occurred during a sortie from Arhus in Denmark to Kalundberg in rough seas and with a strong wind on the port bow. Spray was being constantly blown over the port side of the craft, forming ice over the whole of this side and up the windows, the thickness being estimated at rather greater than 1". This additional weight gradually made the craft too port-side heavy

to operate satisfactorily and it was necessary to stop and remove the ice twice during the journey. The air temperature was $-10^{\circ}C$. Upswept tailpipes were fitted. After their removal, weather conditions changed so comparative tests were not possible.

N6/009 arrived in Sweden with the tailpipe extensions removed and they remained in that state for the whole period in that country. Operations were made over water, snow and ice in a wide variety of air temperature conditions but no build-up of ice occurred on the craft.

The plenum heated surfaces were always free of snow or water deposits whilst other surfaces of the craft often collected a layer of snow. It was particularly noticeable that the walkways leading towards the skirts would collect snow since there was a double skin keeping the heat from the snow, but only 2 in. away where the skin formed the plenum no snow settled.

The leading edge of the control surfaces, fins rudders and elevators were normally sprayed with de-icing fluid at the beginning of the day and on no occasion was there an accretion of ice. The forward area of the panniers on each side became crusted with ice up to $\frac{3}{4}$ in. thick on one or two occasions but this was local and showed no sign of spreading. The engine air intake filters were sprayed with anti-freeze liquid each morning. The top intakes appeared to become blocked quite quickly whenever the operation was over snow or slushy ice. The side intakes also appeared to become at least 70% blocked quickly, but after more experience it had to be concluded that the blocking with this wet snow was not as severe as it appeared, since the performance of the engine did not change at all.

From the foregoing considerations it was concluded that none of the operation over water in Sweden had been at a low enough temperature to cause ice build-up on the craft. Whenever SR.N6 had been out in really low temperatures free water was not to be found. An aerial reconnaisance to the north and east of Soderhamn showed that there was no real possibility of getting to water in that direction, since an enormous ice barrier often 10 ft. to 30 ft. high ran more or less parallel with the coast about 7 miles to eastwards, see figs.16 and 17. Schemes were prepared to fit simple trial installations of de-icing systems as discussed below and it was arranged to blow up the ice locally when these were ready.

6.3.1. De-icing fluid

Only B.P. De-icing Fluid, type 2 was available but this had proved of considerable value in Norway and Denmark and it was arranged to spray this on the leading edges of the control surfaces, and over the engine air intake filters.

6.3.2. Hot air de-icing

A simple combustion heater was fitted into the main cabin and the hot air outlet was ducted through a window to the air space which had been provided by fitting a second skin over one section of the port

plenum structure. See fig.18 and 19.

6.3.3. Flexible skin

In order to compare the build up of ice on solid skin with a flexible material a sheet of nylon type material was attached to a section of the port plenum in the same double skin manner as 6.3.2.

6.3.4. Pneumatic installation

A simple pneumatic de-icing mat was constructed and attached to the port pannier forward face and side, see fig.20. It was connected to air bottles by way of reducing and control valves in the cabin. The cyclic switching was controlled manually.

6.4. RESULTS OF DE-ICING SYSTEM TESTS

The fitting of the de-icing equipment occupied two days, during which the weather unfortunately became much warmer. However, one sortie was made to check that the installations functioned, and a second sortie was flown early in the morning after a large hole had been blown in the ice. Although the air temperature was just below zero at this time, hovering in the wet area produced no icing of the craft. Later at Saltsjobaden a further early morning sortie was flown at air temperature of -5°C, and after 15 minutes hovering over water a thin film of ice up to 0.1 in. thick was appearing on the craft. The areas which had been selected for test purposes did not build up ice, but this did not appear to be due to the de-icing properties of the system, but possibly due to the flexible skin. In this respect flexible skins as de-icing systems may be worth more investigation.

The inability to find the right conditions to generate heavy ice on the structure limited to a great extent the results or developments which might have arisen. It is worth noting, however, that conditions of very low air temperature, say -10°C, with the sea unfrozen, cannot be nearly as common in areas where hovercraft may wish to operate as would be the case for ships. If there is a choice for the hovercraft to operate over ice or water it may well take the former; a ship has not this choice.

6.5. ENGINE AIR INTAKE FILTERS

As stated previously these filters appeared to become blocked or partially blocked very quickly when operating over snow or snow-covered ice, but this was not a freezing blockage, (anti-freeze liquid was on all occasions used generously),nor could it be considered a serious blockage since engine performance was not affected. However, it was decided to fit a trial installation of an engine air delivery duct from the craft's plenum chamber. The scheme had been tried experimentally on SR.N5 craft, both for cold weather operation and other air filtering purposes.

The intake ducts had been made at Malmo but a decision to fit them was deliberately delayed, since the main cabin heating system would probably not be usable, due to the fact that the air entering the engine

would be contaminated by exhaust gases, consequently contaminating the cabin hot air supply which is taken from the engine compressor.

The ducts were fitted just before taking the craft up off the ice on to land one afternoon when the filters were all in a snow-sodden condition. After the engine had been started, trpm was increased to a high order to go over a rough area, the top filter suddenly cleared itself of snow and slush quite spectacularly, a fine cloud of mist, 'steam', water and anti-freeze liquid being blown out over the top of the craft. This pressure, probably 3 in. or 4 in. of water, was of course rather higher than would be expected when cruising at normal trpm conditions. Measurements on SR.N5 have shown a pressure in the engine bay of approximately $\frac{1}{4}$ in. water at 40 kt. with the top intakes open.

A sortie on the following day showed that all three intake filters were being kept spotlessly clean with this type of air supply for the engine. However the pilot found that he was not able to obtain the same high trpm with propeller pitch angles of approximately 7 deg. that he was obtaining without the new intakes. A quick check revealed that the power from the engine was lower, as would be expected due to the much higher engine air intake temperature. The apparent loss of power was much more noticeable, since under the cold conditions in which all the operations were being made, a much higher than normal power rating was being obtained. It was confirmed that the cabin air heating system could not be used, the air from the compressor being smoky and smelly. A feature of the plenum intake in the SR.N5 was that it appeared to move slightly the Cp of the cushion requiring retrimming on the craft. This was not noticed on SR.N6, but the tests were made over ice and not water as in the case of the SR.N5.

It was generally concluded that this type of engine air supply was an excellent second string to have ready if filter blocking became really serious, but that it was better not to use it indiscriminately, as besides causing loss of power, it fouled the engine quite quickly, and the cabin remained cold.

7. SORTIES FROM SODERHAMN TO STOCKHOLM

7.1. GENERAL

The plan for the last week of the trials period was to return from Soderhamn to Saltsjobaden during Monday and Tuesday, March 21st. and 22nd. and to devote the remainder of the week to demonstrations of the craft to members of various Swedish shipping companies. In fact a certain amount of additional testing also proved possible during the period.

7.2. FROM SODERHAMN TO NORRTALJE

Weather conditions; Wind 10-15 kt. north-west, clear sky, good visibility, temperature just above 0°C. Photographs of ice hills off Soderhamn are given in fig. 21 and 22.

The running times were; To Oregrund, 2 hr. 20 min., from Oregrund to Norrtalje 1 hr. 25 min., giving a mean speed of approximately 42 kt. for each sortie.

7.3. FROM NORRTALJE TO SALTSJOBADEN

Weather conditions : Wind 20 kt., gusting to 38 kt. north-west. Visibility, low cloud and snow storms. Temperature 0°C.

The first 38 n.miles, mainly over smooth ice, were completed at a ground speed of almost 50 kt. Thereafter an area of rough ice, up to 3 ft. high was met, and speed reduced to approximately 25 kt. The final run up to Saltsjobaden was made at almost 60 kt. Total distance, 67 n.miles and mean speed, 32 kt.

7.4. AT SALTSJOBADEN

23rd. March. Further attempts were made to build up ice on the craft whilst hovering over water at an air temp. of -5°C. Also measurements of craft's magnetic signature by visiting Navy officers.

24th. March. Two demonstrations to members of shipping companies.

25th. March. Three demonstrations to members of shipping companies.

26th. March. Sortie to Stockholm harbour and demonstrations in that area. Return to Saltsjobaden

Trials completed on March 26th. and the craft was prepared for shipping to the U.K.

8. CONSIDERATIONS ON THE FUNCTIONING OF THE CRAFT AND SYSTEMS

8.1. GENERAL

In this section of the report it is intended only to review the functioning and suitability of those installations which were either particularly required under cold conditions, or installations which

might have been considered of particular interest under very low temperature conditions. It must be stated however that during the whole trials period the craft operated without any engineering difficulties; all systems were GO at all times. The only major setback occurred one morning when it was found that during the night a PTET warning lamp had disappeared from the instrument panel. A visit to the local Ford agents produced a filament which was usable and the sortie was only slightly delayed.

8.2. CABIN HEATING

This was excellent, except for the valve noise which is most irritating, and was in use on every sortie. It seemed quite impossible to arrive at a set of hot/cold air valve positions to give a warm, pleasant condition which was constant. The usual practice was to open the hot air valve approximately 30% and then, after 10 or 15 minutes when the cabin became too warm, to close the valve to about 10%. This gave a comfortable cabin for 15 minutes, after which more heat was required. The above cycle was generally being repeated at longer or shorter intervals on all occasions. The cabin could never be described as stuffy and there were no complaints of cold feet. The outside temperature varied from $+12^\circ C$ to $-14^\circ C$ and in all cases the general cabin temperature was kept between $20^\circ C$ and $25^\circ C$ which was found very comfortable for sleeping.

8.3. WINDSCREEN HEATING

The centre and pilot's windscreens were fitted with the SR.N6 standard electrically heated glass. This system was in use whenever operating in snow or other conditions which caused cold water, slush, etc. to be thrown onto the craft. The heating proved highly satisfactory in clearing all the snow etc. which was encountered and was helped by an occasional flick of the screen wiper and a spray of fluid to wash the glass. The commander reported that he was most happy with his vision through all the screens in the forward compartment at all times.

8.4. ENGINE INSTALLATION

This was trouble-free apart from the replacement of an IGV actuator quite early in the period. Engine starting was first-time on each of the really cold starts, i.e. $-14^\circ C$, but it was noticeable that the time to light up was longer than normal. Care was taken that a fully charged battery was available for these starts as experience had taught the value of this.

8.5. TRANSMISSION SYSTEM

There were no difficulties; a noisy end bearing on the electrical generator was changed at the end of the period.

8.6. CONTROL SYSTEMS

These remained serviceable at all times; there were no difficulties from cables icing up in fairleads or Teleflex controls freezing even though the craft was soaked down to $-24^\circ C$ during one night.

8.7. ELECTRICAL INSTALLATIONS

These required no attention during the total period of the trials.

8.8. STRUCTURE

No effects of the low temperature or the type of operations were noticeable.

9. RADAR

This separate paragraph has been allocated to the Kelvin & Hughes Type 17 radar installation, mainly for three reasons : (a) its excellent performance in detecting the various types of screw ice and enabling a route to be chosen through it; (b) at least three important, long sorties were made with visibility of 100 yd. or less, when no other craft, air or water-borne, was able to operate; and (c) for its maintenance-free operation in the ice and snow conditions. It was standard practice to switch on the radar as soon as the engine was running, and although the warm-up time was much longer than normal, the operation was always 100%. The most serious maintenance item was to prevent the magnifying screen from becoming frosted over and a habit was made to take this to the hotel with the electrical battery for night storage.

10. SKIRTS

10.1. SKIRT WEAR

A new set of skirts was fitted to /009 in Denmark immediately before the craft was dispatched to Malmo. During the trials in Sweden the craft was lifted three times to inspect for skirt wear. The first lift was at approx. 15 hr., the second at 30 hr. and the third at 50 hr. On each occasion the main skirts were in almost new condition, but after the second lift it was noted that the two heavy sections which form a rubbing area at the jet of the two rear bags, were starting to tear in several positions. At the third lift these rubbing beads were cut away from the rear bags and the jet blanked off. It was most satisfactory to find no skirt damage after the considerable amount of operation over screw ice. It might have been expected that at least some of the sharp jagged edges of the ice would have marked if not cut the outer surface of the skirts, but no signs of this could be found. There were no broken skirt chains or chain anchorages.

10.2 SKIRTS AT LOW TEMPERATURE

Particular care was taken to examine the skirts on arrival at the craft after each very cold night and it was found that in general when the temperature was below -10°C the skirt material was becoming more stiff than normal. Down to -10°C the stiffness was overcome by the skirt weight and inflation would quickly become normal. Within a minute of inflation and air flow, the material was once more flexible. At temperatures lower than -10°C to -20°C the material stiffness was such that the skirts would not take up their shape, and engine running and air flow through them was necessary for 10 or even 20 minutes before full

flexibility was regained. Often one side of the skirts would soften up quickly because of the sun or some other factor but the other would remain hard, so an attempted lift-off resulted in a sideways movement. Patience is the only road to success when wanting to get started for the first time in the morning.

10.3. SKIRTS FREEZING TO SURFACE

The hovercraft was normally left on the ice or snow at night and it was expected that the skirts would be 'frozen on' in the morning. This did not present any undue difficulty. The depth of 'freezing on' depended upon a number of factors such as the state of the ice when the craft was put on it, the amount of day sunshine or snow, and the degree of night frost. Ten or fifteen minutes spent with a trenching shovel freeing the skirt from the ice ensured that no serious sticking was still in force (other than the keel) when the engine was started and the skirts inflated. An ice axe to help free the skirts is also very useful, but it was found that having got an area of skirt free of the ice then it was relatively easy to work a way all round.

It is apparent that a layer of ice also forms inside the skirts during many nights and this makes the material feel much stiffer than it really is. Walking on the skirt (or jumping) produces the satisfying result of hearing the ice inside break up and fall away. This routine became part of the daily inspection.

11. CRAFT MAINTENANCE

It had been anticipated that one of the major results of these trials would have been to demonstrate the difficulties of servicing and maintaining a hovercraft whilst operating away from a home base in very cold weather conditions. In point of fact very little was learnt in this respect as the craft developed no difficulties, and the only work necessary was straightforward routine inspection. Naturally a few 'cold weather golden rules' were quickly developed, e.g. as soon as the after sortie check is complete and the craft refuelled, take out batteries and store in a warm place for the night.

There was no freezing of items such as cowlings, doors, inspection panels and rubber seals, although this type of problem had been expected. Perhaps the ASI pressure head was the most affected item. Original malfunctioning may have been due to icing, but later trouble was probably due to enthusiastic spray treatment with anti-freeze fluid.

During a Daily Inspection, following a 2-hour sortie in a snowstorm during the previous afternoon, a considerable amount of snow was found inside the engine bay, forward of and around the main oil tank. It was not clear whether it had entered during the sortie or during the night. This was the only occasion that snow was found inside either of the air intake filters.

The centre windscreen wiper required minor adjustment on two occasions.

ACKNOWLEDGEMENTS

On behalf of the British Hovercraft Corporation, the writer would like to thank the many people in Sweden who greatly assisted in making the trials a success, and in particular :-

Cdr. E. Friberg of the Swedish Royal Navy
Capt. Bo A.G. Bjernekull, Manager Norrkoping Division, SAAB Aktiebolag
Civil Ingenjor Hans Lundberg, Kockums Mekaniska Verkstads Aktiebolag, Malmo

Fig. 3 OPERATING OVER SMOOTH ICE

Fig. 4 HOVERCRAFT TRACK OVER SNOW-COVERED SMOOTH ICE, AT LOW TRPM

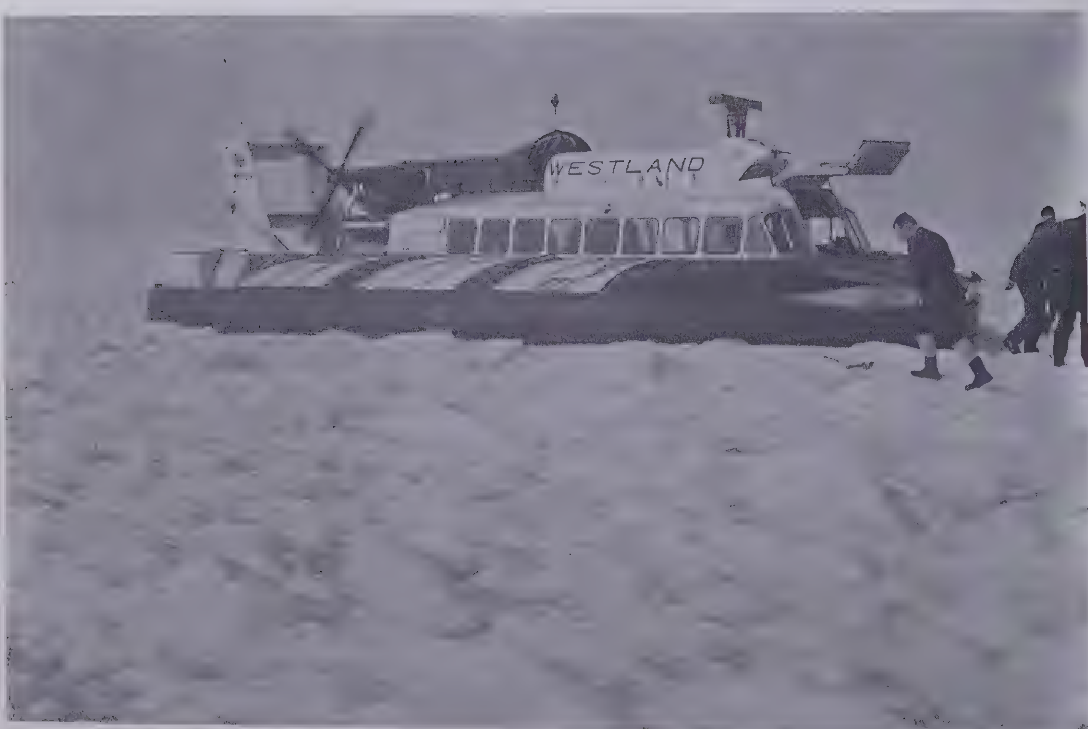

Fig. 5 & 6 TYPICAL ROUGH ICE IN THE MALMO AREA

Fig. 7 OVERLAND OPERATION AT SKANOR

Fig. 8 OVERNIGHT STOP AT SIMRISHAMN

Fig. 9 REFUELLING STOP AT ARKESUND

Fig. 10 THE BASE AT SALTSJOBADEN

Fig. 11 & 12 THE CRAFT AT GAVLE

Fig. 13 & 14 **THE BASE AT SODERHAMN**

Fig. 15 SNOWBALLS REMOVED FROM AFT SKIRTS

Fig. 16 & 17 THE ICE BARRIER EAST OF SODERHAMN

Fig. 18 & 19 COMBUSTION HEATER TRIAL INSTALLATION FOR SKIN DE-ICING

Fig. 20 PNEUMATIC DE-ICING TRIAL INSTALLATION

Fig. 21 & 22 A LARGE ICE HILL OFF SODERHAMN

Fig. 23 & 24 FROZEN-IN SKIRTS

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